

Energy-Efficient Glass Melting - The Next Generation Melter



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DOE Industrial Technology Program



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The Next Generation Melter

- **Goal** - to demonstrate the melting and homogenization stage of a low capital cost, energy efficient Next Generation Glass Melting System
- **Challenge** – to fabricate a 1 ton/h pilot scale melter based on the submerged combustion melting technology and generate homogeneous glass without stones
- **Benefit** – Energy savings, emissions reductions, using a significantly less expensive and more flexible melter
- **FY2005 Activities** –
 - Complete pilot melter, first tests and glass analyses
 - Cold flow model tests to optimize melter flow patterns
 - Working CFD model to assess parameter changes and scale up
 - Lab tests to acquire glass behavior data

Project Sponsors

- U.S. Department of Energy – OIT
- Gas Industry
 - GTI Sustaining Membership Program (SMP)
 - Gas Research Institute FERC funds
- New York State Energy Research and Development Authority (NYSERDA)
- Glass companies each providing cash and technical support
 - CertainTeed Corp.
 - Corning Incorporated
 - Johns Manville
 - Owens Corning
 - PPG Industries, Inc.
 - Schott North America

Project Participants

- GTI
- Glass company consortium (6 glass companies)
- Fluent, Inc.
- A.C. Leadbetter and Son, Inc.
- Praxair, Inc.
- Combustion Tec / Eclipse
- Consultants
 - Leonard S. Pioro - SCM developer
 - Vladimir Olabin – Gas Institute, Ukraine
 - John Brown – glass technology and GMIC contact
- GMIC - monitoring

Barriers, Pathway, Metrics, Benefits

Barriers

- Technical (meeting industry needs)
- Financial (providing large cost savings)
- Organizational (affecting a change in approach to melting practice)

Pathway

- Build and operate 1 ton/h pilot SCM
- Sample and analyze product glass
- Provide cold flow and CFD models supporting SCM approach

Critical Metrics

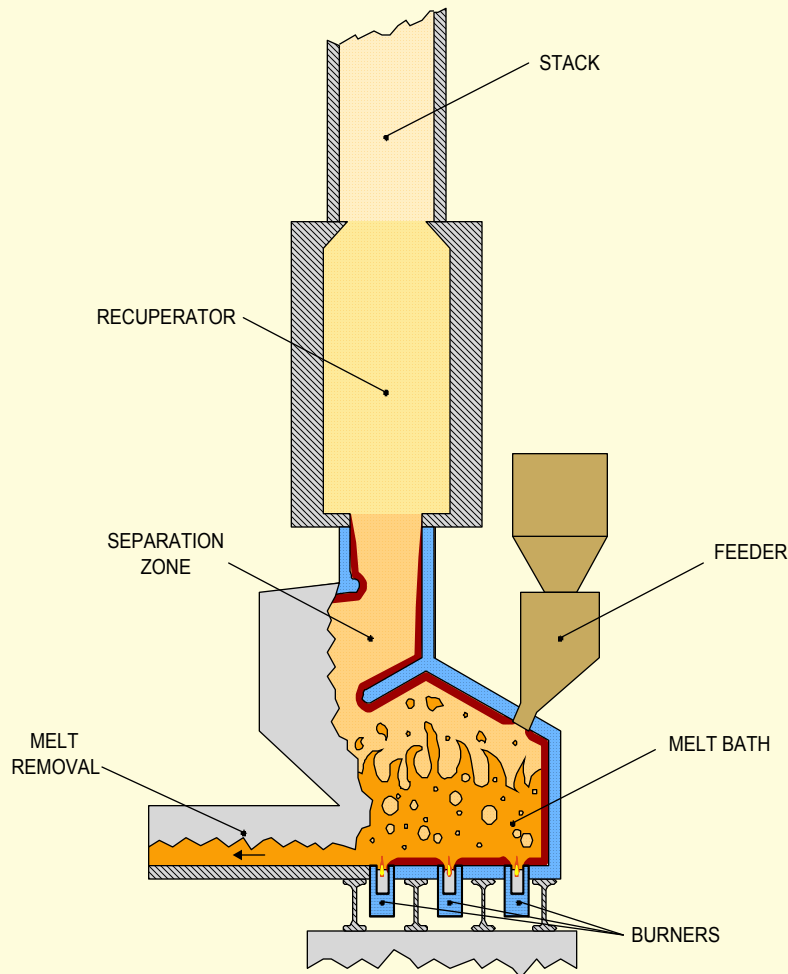
- Material / energy balances (with OTM)
- Glass quality analyses
- Working and validated CFD model

Benefit	
Energy Savings	26 TCF
Capital Savings	\$73 million
Carbon Reduction	0.3 MMTCe
Refractory Reduction	80 %

Requirements for NGMS Melting Step

- Melt all glass compositions
- Scalable from 25 to 500+ tons/day
- Rapid melting (high heat transfer)
- Low capital cost (small size, minimal refractory)
- Long furnace life
- High thermal efficiency
- Homogeneous product (needed for rapid fining)
- Low emissions (CO, NO_x, particulates)
- Stable operation over wide range of pull rates
- Low volatilization of alkalis, borates, etc.
- Reliable, low-cost batch handling and charging
- Foam management
- Redox control
- Physically compatible with rapid fining step of NGMS

SCM Technology



- Oxy-gas firing into the melt bath
 - Intense combustion
 - Direct contact heat transfer - products of combustion bubble through the melt
 - reduced NO_x formation
 - reduced CO and unburned hydrocarbon emissions
 - High rate of heat transfer and rapid mass transfer
 - High thermal efficiency
 - Reduced melter size
- Melter is reliable and robust
 - Low capital cost
 - Externally cooled walls
 - Can be stopped and started easily
- Melting and mixing in one step
- Compatible with other NGMS operations
 - Charging
 - Rapid fining
 - heat recovery

SCM Saves Energy

Melter		Tank	SCM	SCM
Wall Heat Rec., %		0	0	20
Res. Time, h	Melter	--	4.5	4.5
	Fining	--	3.25	3.25
	Total	30	7.75	7.75
Pull Rate, ft ² /ton/day	Melter	--	0.63	0.63
	Fining	--	0.47	0.47
	Total	4.2	1.1	1.1
Surface Area,	Melter	--	15	15
% of tank melter	Fining	--	11	11
	Total	100	--	--
Wall Loss,	Melter	--	0.48	0.39
MMBtu/ton	Fining	--	0.07	0.07
	Total	0.73	0.55	0.46
Total Energy, MMBtu/ton		3.64	3.46	3.37
Energy Savings, %		0	5	7.5

Assuming SCM wall losses of 3 times tank wall losses in Btu/ft².h

Project Schedule

Task		Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Modeling												
2	Melter Design												
3	Procurement												
4	Physical Modeling												
5	Fabrication												
6	Shakedown												
7	Test Planning												
8	Testing - Parametric												
9	Melter Modification												
10	Second Test Series												
11	Analysis												
12	Toward Commercialization												

Progress to Date (first 9 months)

- Completed design and specification of glass batch feed and exhaust gas systems, purchase orders placed
- Space prepared, layout designed, permit in place, steel, electrical, and mechanical bids received
- Equipment for physical Cold Flow Modeling designed and equipment ordering begun
- Critical parameters identified for Fluent CFD modeling
- Subcontracts established with SCM technology experts
- Literature searches continued and translations completed
- Website established to facilitate communications
 - www.glassmelting.com

Pilot-Scale SCM Tests

- Preparations underway for Year 1 tests in batch SCM unit (at right)
 - Tests to evaluate glass melting conditions
 - Feed, exhaust, and sampling systems will be commissioned
 - Samples acquired and analyzed
- Year 2 and 3 tests with new 1 ton/h continuous SCM pilot unit
 - Range of compositions and operating parameters evaluated
 - Comparison with cold flow and CFD modeling predictions
 - Full sample analysis



Major Pilot SCM Components

Vacuum unloading system	Pilot SCM melter
Loss in weight system	Roura hoppers (4)
Screw charger	Gas/oxy burners
Vibratory conveyor	Melter control system
Gas/Oxy/Nitrogen control and safety trains	Glass discharge channel with sampling orifice
Baghouse	Sample molds (annealing)
Dilution air fan	Hoists (2)
Exhaust fan	Steel structure
Cooling tower	Misc. chutes and hoppers

Existing Lab Melter

Raw Material Feed

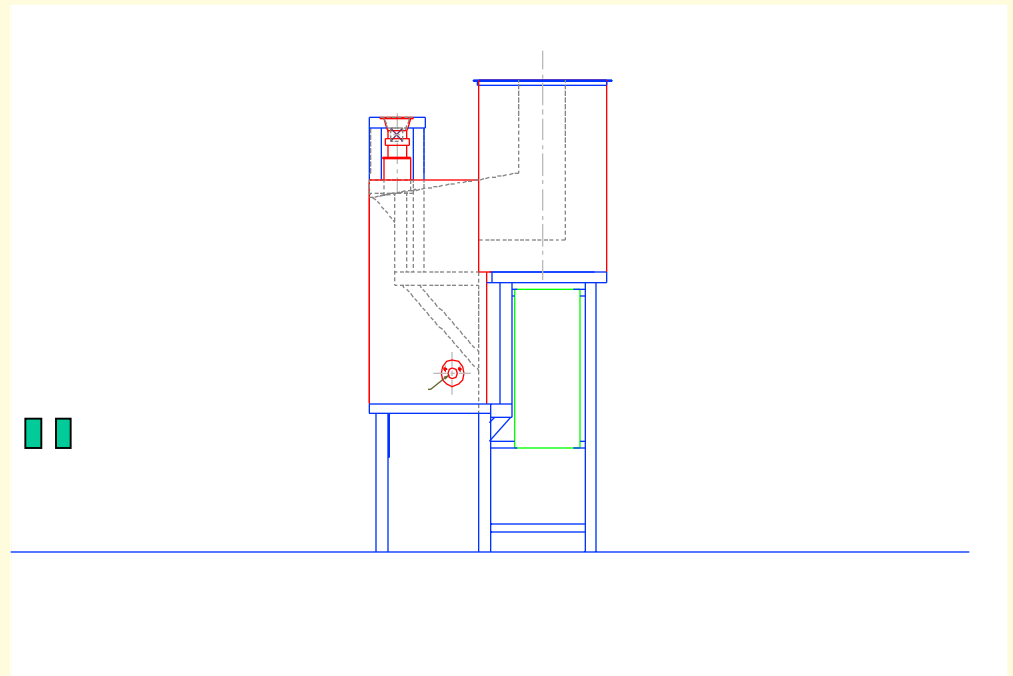
Location

Exhaust Gas Location

Glass Discharge

Submerged Combustion
Burners

Control Panel



Glass Batch Unloading System

Bulk Bag Discharge Frame and Hopper

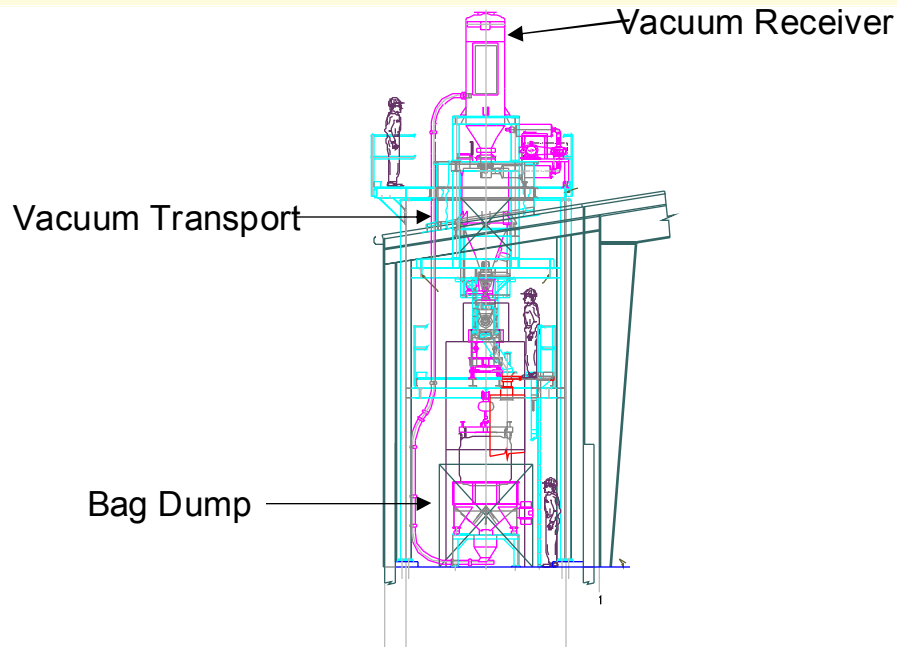
Accepts “super sacks” of premixed glass batch raw materials

Vacuum Transport and Elevation System

Blower creates vacuum in delivery pipe to transport raw material

Vacuum Receiver Chamber

Hopper receives raw material and completes unloading cycle



Glass Batch Weigh and Feed System

Loss In Weight Bin

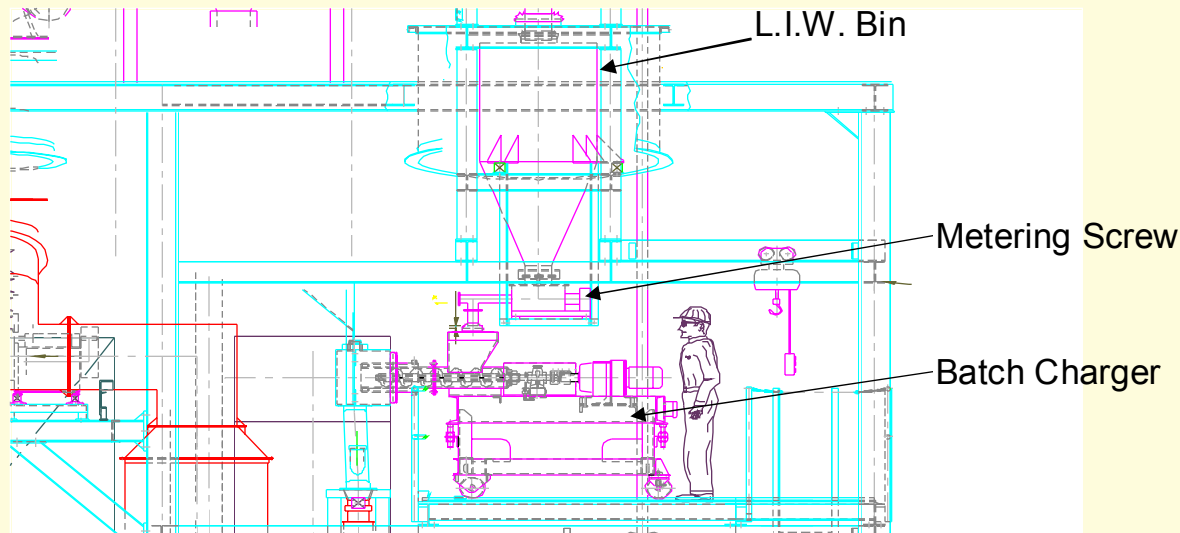
Cone shaped hopper mounted on load cells

Metering Screw Auger

Variable speed auguring screw controls raw material discharge

Screw Feeder Batch Charger

Main auguring screw to convey raw materials into melter



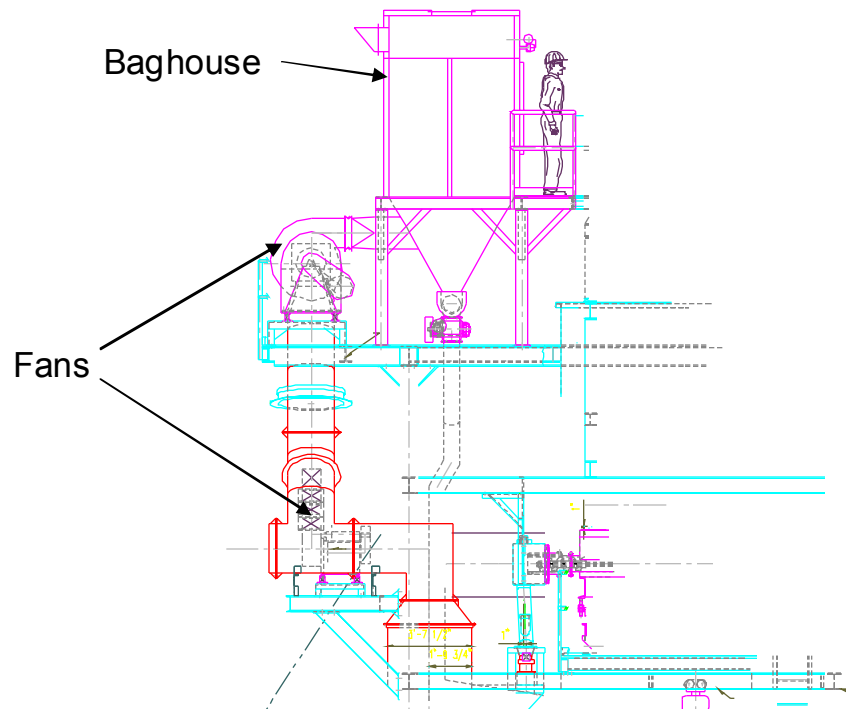
Melter Exhaust and Dust Collector

Exhaust Fan/ Dilution Air Fan

Draws gaseous products of combustion from melter

Baghouse/Dust Collector

Filters exhaust gas to remove solid particulate



Melter, Feed, and Exhaust Controls

Control Equipment	Power Supply	Field Devices
8 channel analog input card	RSLogic 5000 PLC	Furnace transmitters
6 channel T/C card	RSView software	Actuators
8 channel output card 4-20 mA	Dedicated PC	T/Cs – duplex
16 channel 120VAC digital input card	PLC panel	T/Cs - triplex
16 channel 120VAC digital output card		WFD for furnace pressure
DH + R10 adapter module		Combination starters
Ethernet communication module		Scale interface logic
10 slot control logix chassis		
Control Logix PLC IM memory		

Melting Tests for FY2004

- Batch tests in existing melter before 9/30/2004
- First test will be with a soda-lime batch
 - Feed and exhaust systems will be commissioned
 - Glass sample collection and analysis
- Second test will be with e glass batch
 - Glass sample collection and analysis
 - Results used for pilot melter design and input into modeling

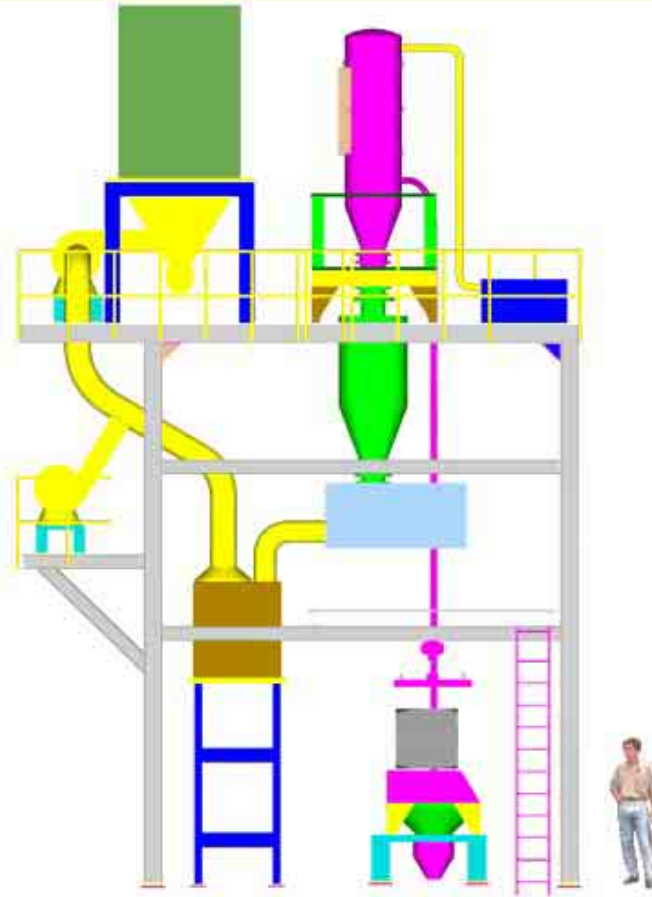
Glass Sample Lab Analyses

- Glass Devitrification Analysis
- Glass Metal Contamination Analysis
- Glass Homogeneity Analysis
- Seed Quantity and Size Distribution Evaluation
- Unmelted Batch/ Stone Evaluation
- Glass Batch Volatilization Evaluation

NGMS Pilot Melter Installation



NGMS Pilot Melter Installation



Differences Between SCM and Traditional Glass Melting

- Combustion and flame formation radically different
- Gas flow through burners must overcome hydrostatic head of molten glass
- High speed shear flow and bubble formation/break-up with gas diffusion
- Forced convection heat transfer vs. buoyancy driven flow in a traditional glass furnace
- Presence of highly turbulent flow (gas) in the vicinity of low Re laminar, viscous flow (glass)
- Presence of cold walls and formation of a semi-solid glass layer (due to cooling water flow)

Modeling of SCM Furnace

Complete modeling of SCM will require:

- ✓ CFD model for molten glass flow and heat transfer
- ✓ Gas bubble formation and reaction/diffusion in bubbles
- ✓ Multiphase model for gas/liquid/solid flows
- ✓ Combustion/reacting species transport model with multiphase flow
- ✓ Turbulence modeling with multiphase flow
- Granular multiphase model for batch feeding
- Batch melting model with reaction kinetics and multiphase flow
- ✓ Conduction, convection, and radiation heat transfer model
- ✓ Couple radiation from the gas phase to molten glass
- ✓ Ability to model gray-band radiation with variable absorption coefficients
- Mass transfer from bubble surface to glass melt and vice-versa
- Gaseous reaction/diffusion in bubbles and dissolution in molten glass
- Needs model enhancement or development
- ✓ Currently available in FLUENT

SCM Modeling Approach in FLUENT

- First task will be to model bubble formation and convective flow/heat transfer w/o combustion → this will give overall furnace flow and temperature distribution
- Next, combustion and gas diffusion in bubbles will be modeled → this will provide information about flame shape and heat transfer to the glass melt
- Next, Eulerian multiphase model will be used with chemical reactions (more rigorous approach) → solves Navier-Stokes eqn. for each phase
- Radiation from gas bubbles to glass melt and internal radiation within glass will be modeled
- Next, mass transfer and diffusion from one phase to another will be modeled
- Batch melting model added for complete SCM modeling

Developments Needed in FLUENT

- Coupling of Discrete Ordinate (DO) radiation model with Volume Of Fluid and Eulerian multiphase models
- Batch melting model implementation with Granular multiphase model
- Implementation of mass transfer model for gas diffusion and dissolution in molten glass (currently done via User Defined Function)
- Improvements in coupling of turbulent flow with multiphase models for strong secondary phase turbulence
- GUI development for ease of problem set-up

Suitability of FLUENT for SCM Model

- Unique combination of reacting Volume of Fluid (VOF) model and reacting Eulerian multiphase model
- Availability of state-of-the-art Discrete Ordinate (DO) radiation with gray-band model and variable absorption coefficients
- Ability to model internal radiation in glass with semi-transparent interface
- Existing expertise using FLUENT within team (GTI and glass companies)
- Fluent's infrastructure and commitment for long-term support of glass melting CFD, including new enhancements for SCM

Why Physical Modeling

- Provides insights to full scale melter
 - Faster turn around.
 - Reduce scale (physical dimension, temperature, velocity, viscosity..etc.)
 - Low initial and running cost.
 - Easily accessible for quantitative data.
 - Flexibility of evaluating different design concepts and parameters.
 - Validation of numerical models.

NGMS Physical Modeling Objective

- Model molten glass flow patterns in SCM.
- Investigate design parameter effects on the response time/curve
 - Burner positions and operating parameters
 - Height/width/depth of melt
 - Feed and discharge positions
 - Temperature effects on mixing patterns
- Temperature mapping

Dimensionless Groups 1

- Grashof and Reynolds numbers
 - Grashof # $\equiv \frac{l^3}{\nu^2} \beta \Delta T \frac{(inertia)(buoyant)}{(viscous)}$
 - Reynolds # $\equiv \frac{Vl}{\nu} \frac{(inertia)}{(viscous)}$
- Advantage:
 - Match viscosity-temperature curve.
 - Model flow patterns well in traditional glass furnace.
- Disadvantage:
 - Does not take heat transfer into consideration.

Dimensionless Groups 2

- Raleigh, Peclet, and Power numbers

- Raleigh # $\equiv \frac{C_p \rho^2 l^3}{\mu k} \beta \Delta T \frac{(\text{gravity})}{(\text{thermal} - \text{diffusivity})}$

- Peclet # $\equiv \frac{\rho C_p V l}{k} \frac{(\text{heat} - \text{conduction})}{(\text{heat} - \text{convection})}$

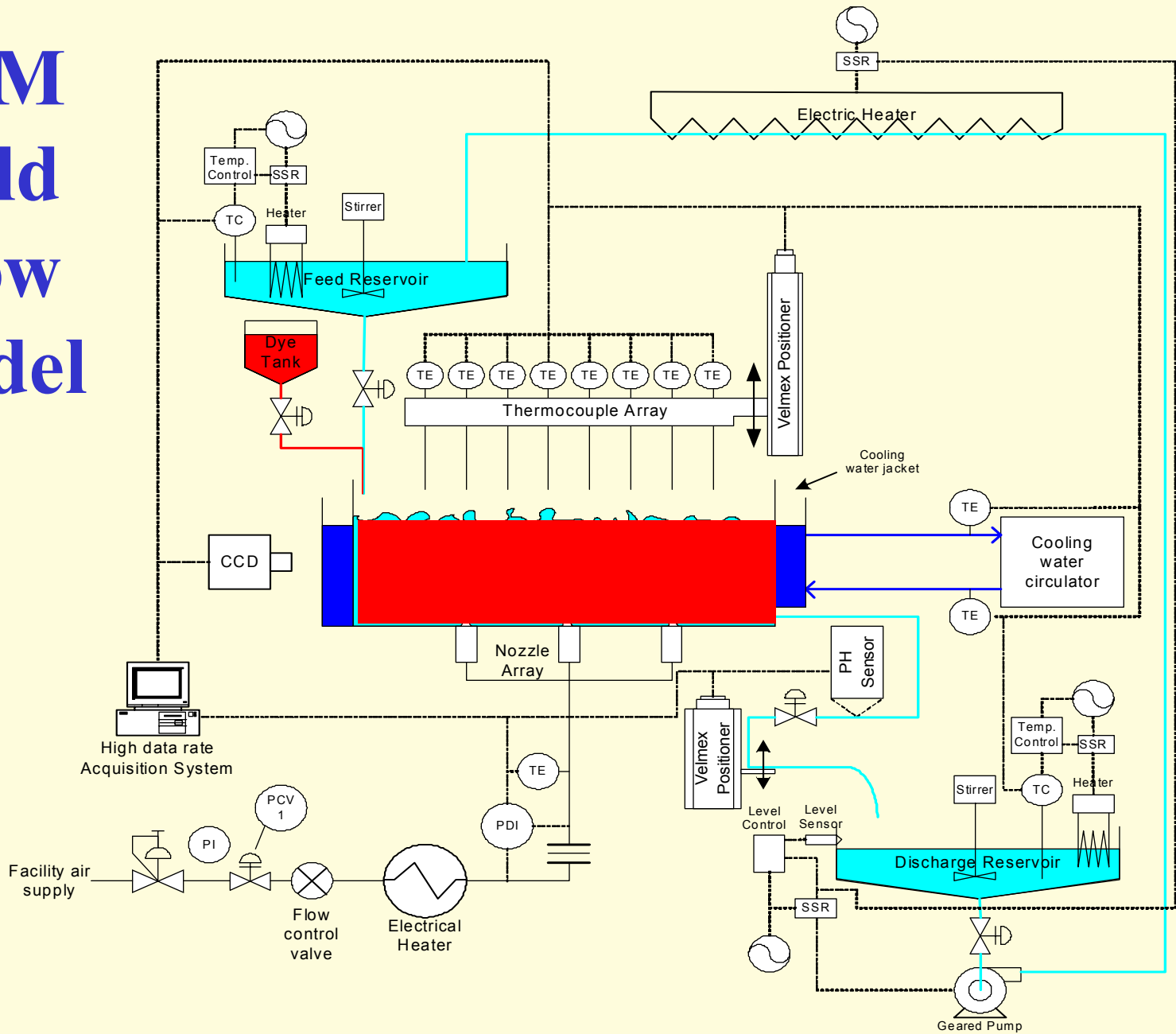
- Power # $\equiv \frac{P}{k l \Delta T}$

- Advantage:
 - Match heat transfer characteristics.
- Disadvantage:
 - Does not match the viscosity-temperature curves between molten glass and model liquid.

Physical Modeling Limitations

- Molten glass surface tension effect.
- Devitrification.
- Melter wall interaction

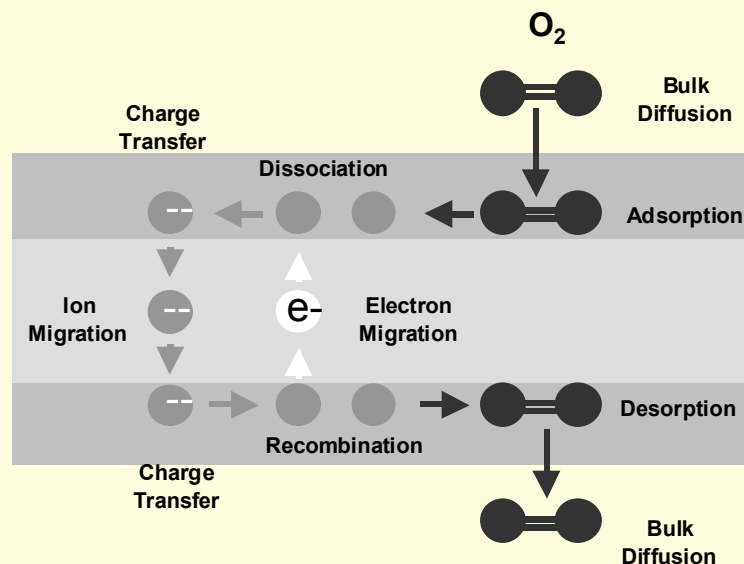
SCM Cold Flow Model



Physical Modeling Status

- A cause-and-effect analysis was conducted
- Two sets of dimensionless groups were identified as potential candidates for physical modeling
- Potential model liquids were identified; their viscosity and temperature ranges were calculated
- Experimental apparatus was laid out. Components were sized, specified and currently under purchase process
- Assembly will commence as soon as the equipment arrives

Praxair Mixed Conductor Transport Mechanism for OTM



- Praxair to evaluate OTM for oxygen production from SCM exhaust gases (+1000°C)
- Subcontract ready for signing – work ready to start
- Praxair work funded by NYSERDA

Consortium Activities

- Meeting Dec. 10, 2003
 - Project planning, assignment of focus areas
- Trip to Europe – GTI, Corning, Owens Corning, GMIC
 - Tours of Sorg and Wiegand Glass
 - HVG/DGG meeting
 - Tour working SCM units in Belarus
- Meeting June 29, 2004
 - Planning for initial batch SCM tests, focus activity initiation
- Lawyers working to finalize consortium agreement

